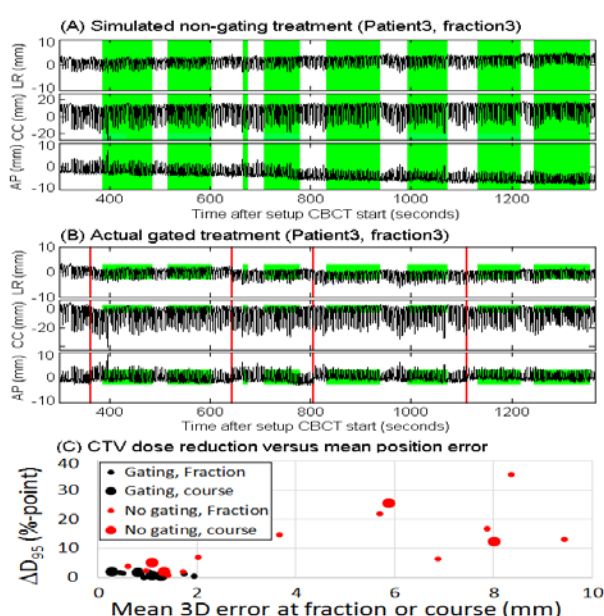


deviate more than -2 mm from the gating window center. Log files provided the transponder motion during beam-on in the actual gated treatments and in simulated non-gated treatments with CBCT-guided patient setup. This motion was used to reconstruct the actually delivered CTV dose distribution with gating and the would-be dose distribution without gating. The minimum dose to 95% of the CTV (D95) for each fraction and each course was compared with the planned CTV D95.

**Results:** Fig. A shows the internal tumor motion at a fraction with large baseline drift of 3mm (LR), 9mm (CC), and 6mm (AP) relative to the pre-treatment CBCT. Fig. B shows the same motion with four drift compensating couch adjustments applied as marked with red lines. The width of the green areas indicates the time of beam delivery. The height indicates the allowed positions for beam-on without (Fig. A) and with (Fig. B) gating. The course mean geometrical error was <1.2mm for all gated treatments, but would have ranged from -2.8mm to 1.2mm (LR), from 0.7mm to 7.1mm (CC), and from -2.6mm to 0.1mm (AP) without gating due to baseline drift. Fig. C shows the CTV D95 reduction relative to the planned D95 versus the 3D mean error for each fraction and course. The mean reduction in D95 for the 12 fractions was 1.1% [range: 0.1-2.1%] with gating and 10.8% [0.9-35%] without gating. The mean duty cycle was 59% [54-70%].



**Conclusion:** Respiratory gating based on internal electromagnetic monitoring was performed for four liver SBRT patients. The gating added robustness to the dose delivery and ensured a high CTV dose even in the presence of large intrafraction motion.

#### PV-0327

##### Patient-specific motion management and adaptive respiratory gating in Pancreatic SBRT

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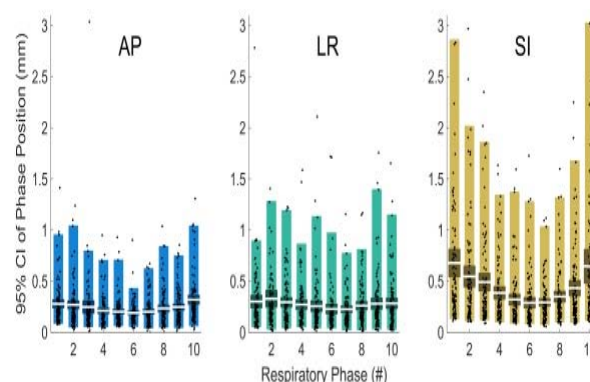
**Purpose or Objective:** Ablative radiotherapy is rapidly emerging as an effective treatment for locally advanced pancreatic adenocarcinoma. However, the pancreas undergoes erratic and unstable respiratory-induced motion, which decreases coverage of the tumor and increases dose to the duodenum. The purpose of this study was to develop and optimize motion management protocols which allow for safe delivery of pancreatic SBRT.

**Material and Methods:** We analyzed 4DCT and CBCT data from 35 patients who received pancreatic SBRT; the majority were locally advanced tumors receiving 30 Gy in 5 fractions.

In total, the data from 175 treated fractions was analyzed. For each fraction, the daily trajectory of the tumor was reconstructed by calculating a Gaussian probability density function using the location of gold fiducial markers in the CBCT projections. These trajectories represented over 600 samples of the position of the tumor during the course of CBCT acquisition. Using the calculated trajectories, we investigated the dosimetric impact of several respiratory motion management strategies, including gating based on instantaneous kV imaging of implanted fiducial markers.

**Results:** 4DCT was a poor predictor of pancreatic motion, as the amplitude of daily motion exceeded the predictions of pre-treatment 4DCT by an average of 3.5 mm in the SI direction. In a Fourier-based analysis, these uncertainties were correlated with an increase in low-frequency motion (potentially due to peristalsis of the duodenum). Abdominal compression increased the consistency of motion and reduced the amplitude by  $2.7 \pm 2.8$  mm. On average, respiratory gating decreased the apparent motion even further, with attainable effective motion amplitudes of 2 mm. However, gating based on external surrogates (either phase- or amplitude-based) is greatly hindered in some patients by the inconsistency of pancreatic motion. In these cases, internal gating surrogates are warranted. In a simulated clinical scenario, fiducial-based internal gating using a 2 mm SI window greatly outperformed conventional gating using external surrogates ( $p < 0.001$ ), with a mean target D95 of  $99 \pm 2\%$ , 95% CI 93-100% (conventional gating - D95  $97 \pm 7\%$ , 95% CI 68-100%). Additionally, we analyzed the dosimetry of motion by convolving the dose distribution with phase-specific motion information. Using these data, we developed a metric that predicts patient-specific consistency, and in a simulated adaptive protocol which adjusted margins based on this metric, there were significant increases in mean target D95 and minimum dose.

**Conclusion:** Motion management is essential in reducing the size of target volumes and minimizing dose/side effects to the small bowel. Motion uncertainties and patient-specific differences warrant an adaptive approach to respiratory management. Our data shows that using real-time kV imaging of implanted fiducial markers to adapt the gating protocol based on the instantaneous position of the tumor outperforms conventional approaches.



#### PV-0328

##### Rectal immobilisation device in stereotactic prostate treatment: intrafraction motion and dosimetry

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**Purpose or Objective:** PROMETHEUS (UTN: U1111-1167-2997) is a multicentre clinical trial investigating the feasibility of stereotactic radiotherapy (SBRT) as a boost technique for

prostate cancer. The objective of this sub-study is to evaluate infraction motion, using cine MRI, and the dosimetric impact when using a rectal immobilisation device (RID).

**Material and Methods:** The initial 10 patients recruited underwent planning CT and MRI, with and without a RID. Cine MRI images were captured using an interleaved T2 HASTE sequence in sagittal and axial planes with a temporal resolution of 5.4 seconds acquired over 4 minutes, the average time for a single SBRT VMAT fraction. Points of interest (POI) were outlined by a single investigator and a validated tracking algorithm measured displacement of these points over the 4 minutes in the anterior - posterior, superior - inferior and left - right directions (Figure 1).

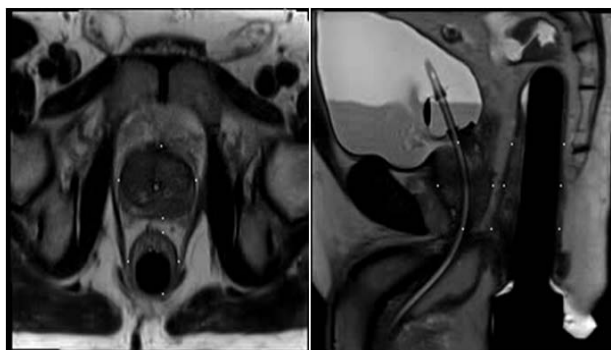


Figure 1: Axial and sagittal MRI slice showing Points of Interest (white dots)

Planning CT and MRI scans were fused and contoured by a single investigator. They were planned using a VMAT technique to 19Gy in 2 fractions by a single investigator. The planning priority set for the non - RID plan was to match the coverage achieved in the RID plan. Dose Volume Histogram results of both plans were analysed.

**Results:** There was an overall trend for increasing POI displacement in all directions as time progressed when no RID was insitu. POI remained comparatively stable with the RID. In the sagittal plane, the RID resulted in statistically significant improvement in the range of anterior - posterior displacement over the entire 4 minutes of the inferior anterior and posterior rectal wall (both  $p < 0.001$ ), mid anterior and posterior rectal wall (both  $p = 0.007$ ), anterior prostate ( $p = 0.019$ ), prostate apex ( $p = 0.003$ ) and prostate base ( $p = 0.011$ ).

The RID also resulted in improvement in range of superior - inferior displacement of the inferior posterior rectal wall ( $p = 0.002$ ), mid anterior rectal wall ( $p = 0.043$ ) and posterior rectal wall ( $p = 0.023$ ).

In the axial plane, the RID resulted in statistically significant improvement in the range of anterior - posterior displacement of the anterior rectal wall ( $p = 0.008$ ) and posterior prostate ( $p = 0.011$ ).

For all these points, the RID approximately halved the range of displacements, with some points moving over 2mm when no RID was insitu.

Dosimetrically, the use of a RID significantly reduced rectal V16 (0.27cc vs 1.71cc;  $p < 0.001$ ), V14 (1.12cc vs 2.32cc;  $p = 0.02$ ) and Dmax (15.72Gy vs 18.90Gy;  $p < 0.001$ ), as well as percentage of posterior rectal wall receiving 8.5Gy (7.38% vs 12.20%;  $p = 0.003$ ). There was no statistically significant difference between bladder or urethral Dmax, CTV D98 or conformity index between both plans.

**Conclusion:** The rectal immobilisation device used in stereotactic prostate radiotherapy leads to reduced intrafraction motion of the prostate and rectum, with increasing improvement with time. It also results in significant improvement in rectal wall dosimetry.

#### PV-0329

##### Modulation indexes for predicting interplay effects in lung SABR treatments

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**Purpose or Objective:** The purpose of this study was to analyze the modulation indexes proposed in the literature for predicting interplay effects in lung SABR treatments

**Material and Methods:** 23 SABR plans (4 arcs of 200°-220° for 6MV and 2 arcs for 10 MV FFF) calculated on Eclipse V10.1 (Varian) were analyzed with the Quasar respiratory phantom (Modus Medical Devices) by comparing dose distributions on EBT3 radiochromic film. Static and dynamic irradiation at 0.5 cm amplitude (1 cm peak-to-peak) and 12 breaths per minute (BPM) was used. 18 plans were irradiated in a Silhouette LINAC with 6 MV and 5 on a TrueBeam (Varian) LINAC with 6 MV FFF. The acceptance criteria was set to be  $< 5\%$  of points with  $\gamma(3\%, 3\text{mm}) > 1$  on the comparison between static and dynamic dose distributions. A threshold of 90% was fixed since the aim was to study the influence of the modulation on the ITV. The modulation indexes analyzed were: The Modulation Complexity Score (MCS)-McNiven 2010; the Modulation Index Total (Mit)- Park 2014 which introduces speed and MLC acceleration and finally the Aperture Irregularity (AI) -Du 2014 which analyzes the non-circularity of the MLC apertures. A Matlab (Mathworks) program was developed to calculate them. Finally, the PUMA method, which is based on splitting arcs in the TPS and modeling movements by changing their isocenter positions, was also used. Possible linear correlation between these indexes and radiochromic films was analyzed and a statistical analysis performed.

**Results:** Modulation indexes are shown in Table 1. A statistical analysis of the goodness of fit was done; which found only significant linear correlation ( $p < 0.0001$ ) between film-PUMA, film-Mit and also between PUMA-Mit. A positive plan is considered to be a plan suitable for treatment when evaluating the interplay effect. A value of 0.6 for the Mit index is proposed as the upper limit. This value was selected in order to minimize the number of false negative plans. Mit and PUMA have the same specificity (100%) since both detected all of the failing plans. However, PUMA has a greater sensitivity (95% vs 85%).